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Limited Angle Tomography Using Volumetric Constraints

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Summary

The imaging system conventionally used for Computerized Ionospheric Tomography (CIT) [1] is an example of a limited angle tomography system. The aim is to image the electron density distribution of the ionosphere in the two-dimensional plane lying between a satellite orbit at an altitude of 1000 km and a co-planar chain of ground station receivers as shown in Figure 1.

The ionosphere lies approximately in the 80 — 500 km altitude range. As the satellite passes over head it sends dual frequency radio signals at 150 and 400 MHz respectively which undergo different amounts of Doppler phase shift along each ray path before they are simultaneously received by the ground stations. The difference of Doppler shift encountered by each received signal sample is subsequently processed to obtain information about the total electron content (TEC) of the ionosphere along the corresponding ray path. TEC records for parallel ray paths are grouped together as samples of pseudo tomographic projections, and used to reconstruct the ionospheric plane electron distribution with the aid of different tomographic image reconstruction algorithms [3,4,5]. The result of missing horizontal rays is that reconstructions lack considerable distribution information in altitudinal direction [6]. Hence, it is difficult to locate absolute heights of important electron formations such as peaks and troughs [2] as shown in Figure 2.
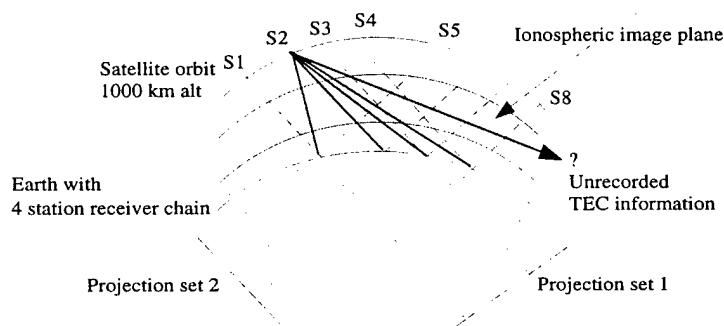

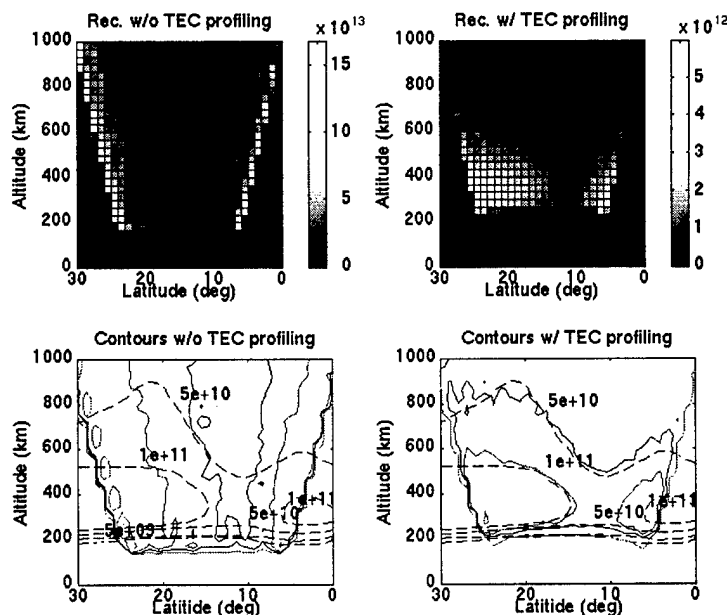Figure 1. CIT imaging system geometry.

Figure 2. Image reconstruction without and with volumetric correction.

Many current reconstruction algorithms use information from model ionospheres such as IRI-90 [2] to supplement the measured TEC data for reconstructions with better shape definition and background support, while several others use a priori free reconstructions involving smoothness constraints and extremal nullity. Many of these algorithms employ a priori or mathematical constraints on a global basis with little scope for regional adjustments or allowances for unique and unexpected features of the measured ionosphere which are not completely representable with known structural or behavioral information.

The Volumetric Constraints approach to CIT image reconstruction introduces weighted correction values, based on local deviations of the current image from a priori parameters, during each cycle of a simultaneous iterative reconstruction (SIRT) process. The fundamental and modified steps of Volumetric SIRT (VSIRT) reconstruction are shown in Figure 3. Volumetric or shape correction of the reconstruction is performed at two stages during a given iteration of the algorithm. The first instance occurs during the redistribution of the difference between TEC values and those calculated for corresponding rays from the currently known image. The second instance involves volumetric shaping in the image domain after TEC based correction has been made. The shape of an image is defined to be the

normalized convolution product between the image and some form of smoothing mask. Ionospheric electron distribution patterns typically yield very smooth low frequency images, hence the mask chosen for shape extraction is a large circular smoothing template which preserves large scale significant variations while eliminating minor local differences that might arise in individual images.

This corrective action in both the projection and image domains in each iteration aims to achieve a balance between one-dimensional distribution patterns along individual ray paths and two dimensional ones suggested by the position, extent and electron density of various ionospheric layers. In each instance a normalized weight vector is used to simultaneously reinforce the natural shape of the reconstruction and direct it towards that of the most probable combination of a priori features. Thus localized reconstruction of features most favored by actual measurements is substantiated with relevant a priori support both in the projection and image domains. The actual location, extent and electron density of ionospheric formations in the reconstructed image is validated by rescaling relevant portions of the image to satisfy simulated "on site" ionosonde and ionospheric backscatter sounder information.

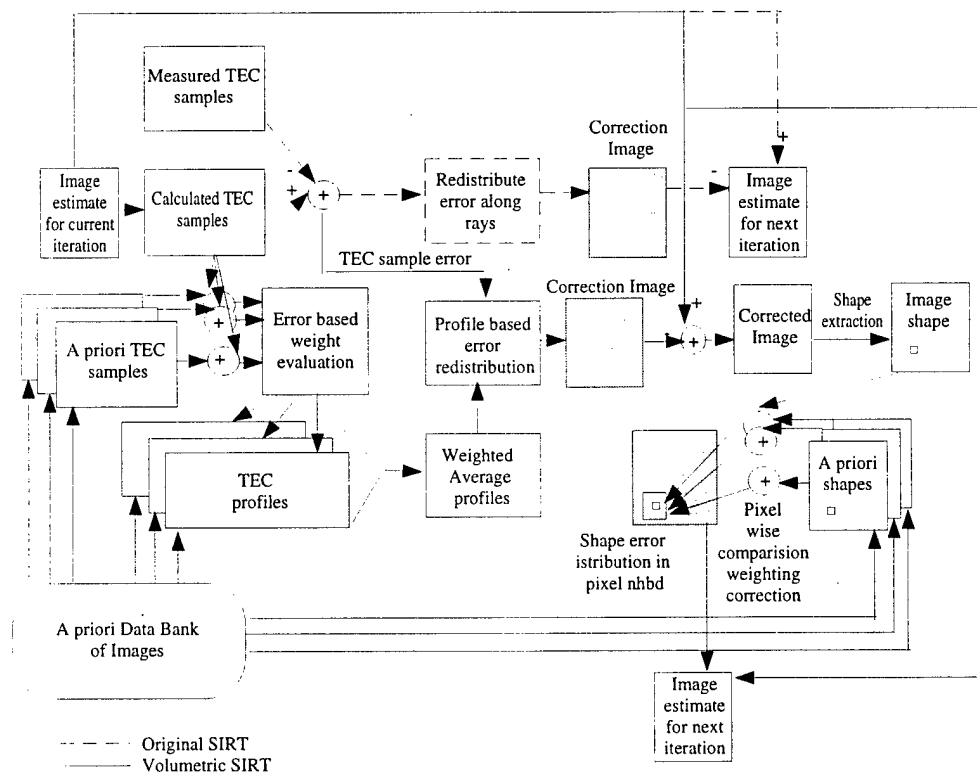TEC data obtained from simulated IRI-90 model

Figure 3. The Volumetric Simultaneous Iterative Reconstruction Algorithm.

images were used to form reconstructions based on several different types of test suites. Figure 4 shows two such test suites and the reconstructions derived from them. In each case, the contours of the original image are shown in the background as dashed lines, enabling comparison of reconstructions. Also, the test image contours show how different the a priori sets are from each other and the original, thus supporting the claim that volumetric reconstruction, by nature, provides substantial data directed conformity. In particular comparision of the reconstructions of Figure 4 with the non-volumetric reconstruction of Figure 2 shows the improvement contour conformity achieved in the latter. The vertical position and extent of the peak between 20–30° latitude is clearly defined in the volumetric reconstruction. Within figure 4, the a priori set on the left hand side has more similarities with the test image than the right hand one. However, reconstructions relying on either set show substantial conformity with the test image, showing how VSIRT selects the most likely volumetric distribution pattern even from a diverse and dissmilar suite of a priori images. More test cases will be analyzed and presented in the complete version of this paper.

References

1. Austen, J. R., S. J. Franke, and C. H. Liu, Ionospheric imaging using computerized tomography, *Radio Science*, 23(3), 299–307, 1988.

2. Davies, K., *Ionospheric Radio*, P. Peregrinus Ltd., London 1990

3. Raymund, T. D., Ionospheric tomography algorithms, *Int'l. J. Imag. Systems & Technol.*, 5(2), 75–85, 1994.

4. Raymund, T. D., S. J. Franke, and K. C. Yeh, Ionospheric tomography: its limitations and reconstruction methods, *J. Atmos. & Terr. Physics*, 56(5), 637–757, 1994.

5. Sutton, E. and H. Na, Ionospheric tomography using the residual correction method, *Radio Science*, 31(3), 489–496, 1996.

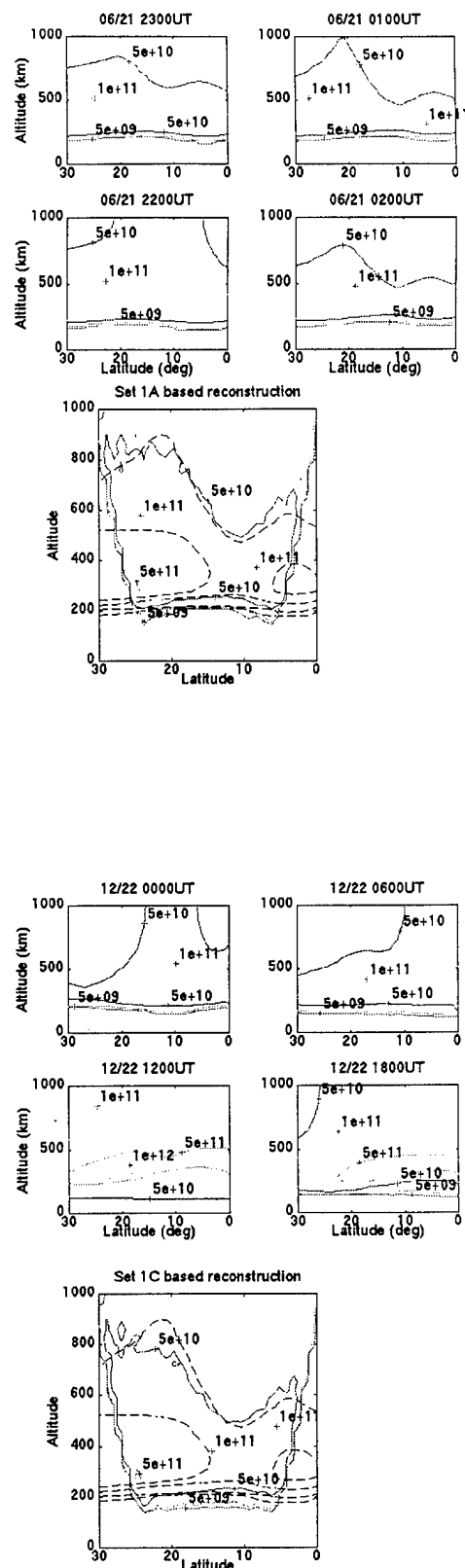6. Yeh, K. C. and T. D. Raymund, Limitations of ionospheric imaging by tomography, *Radio Science*, 26(6), 1361–1380, 1991.

Figure 4. A priori sets 1A and 1C with reconstructions.